Constraining Early Dark Energy with Galaxy Clusters

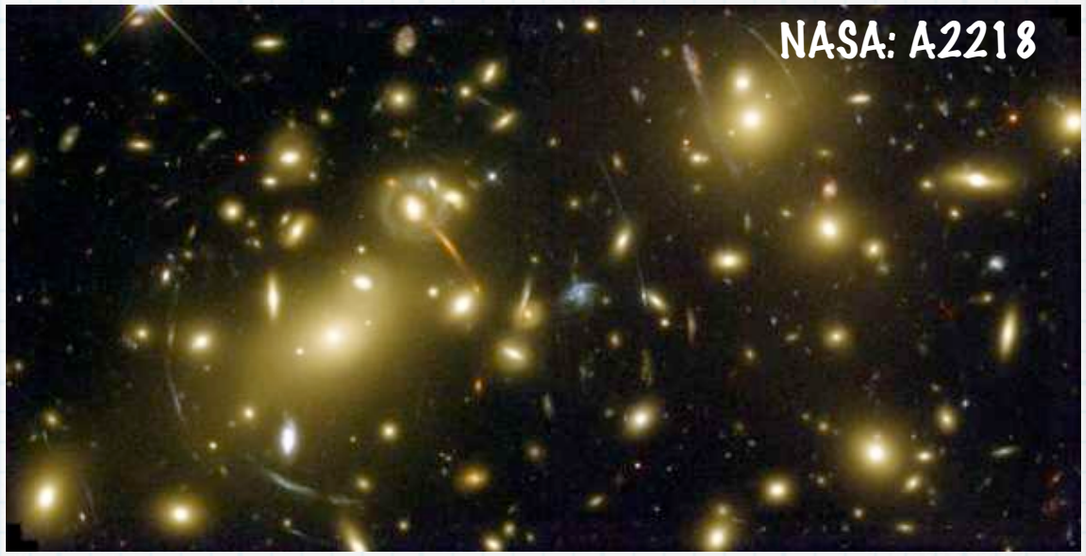
Zarija Lukić (Los Alamos)
with
Ujjaini Alam and
Suman Bhattacharya

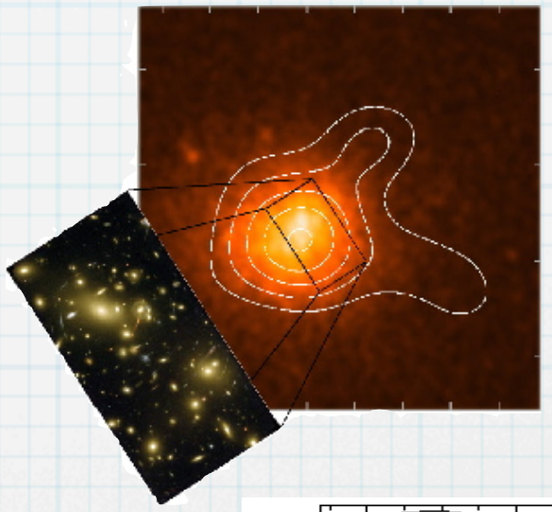
Cosmology & galaxy clusters

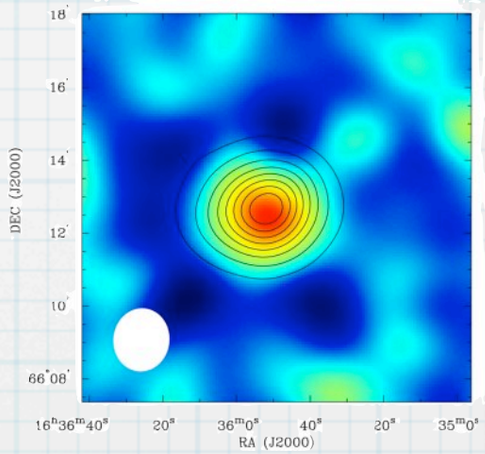
- Galaxy clusters are the heaviest and most recently assembled virialized objects.

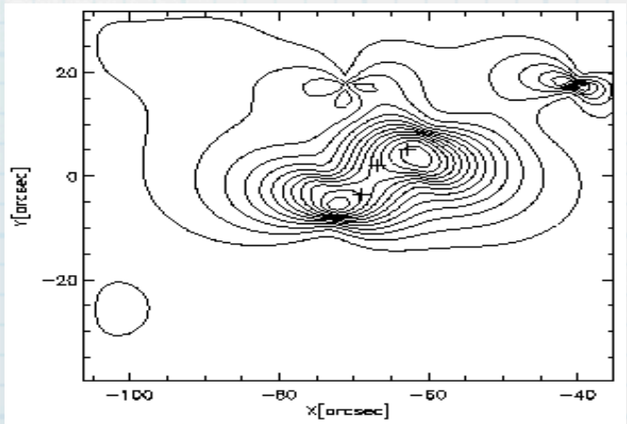
- Their abundance and spatial distribution are sensitive to cosmological parameters, and in particular the amount and properties of dark energy.

- Observational campaigns have just started, or will start soon (SPT, ACT, Planck, DES, eROSITA)









Two of the probes

eROSITA wide survey:

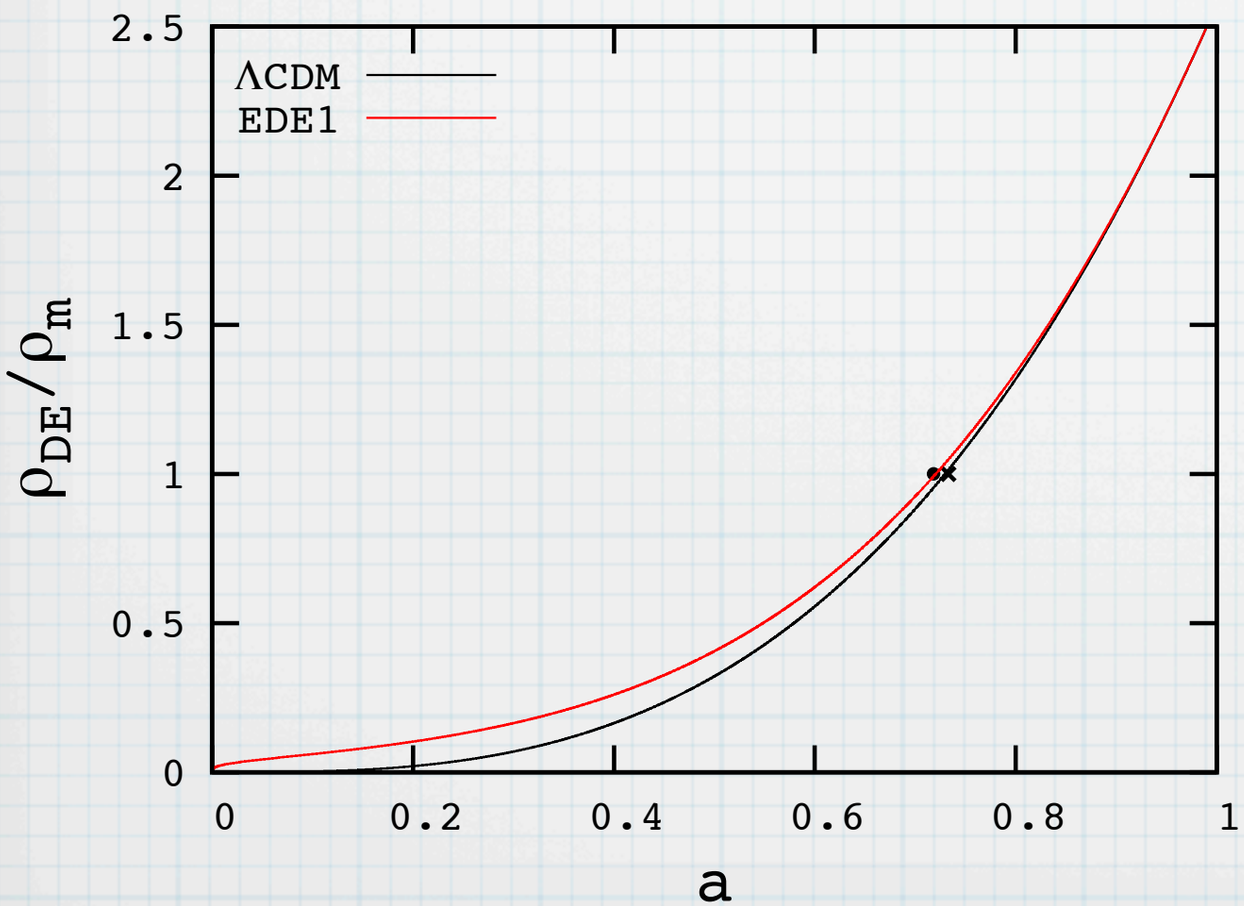
- X-ray emission
- Band: 0.5-5 keV
- Start date: 2012
- Sky coverage: 20,000 deg^2
- $S_{min} = 3.3 \times 10^{-14}$ erg/cm^2s

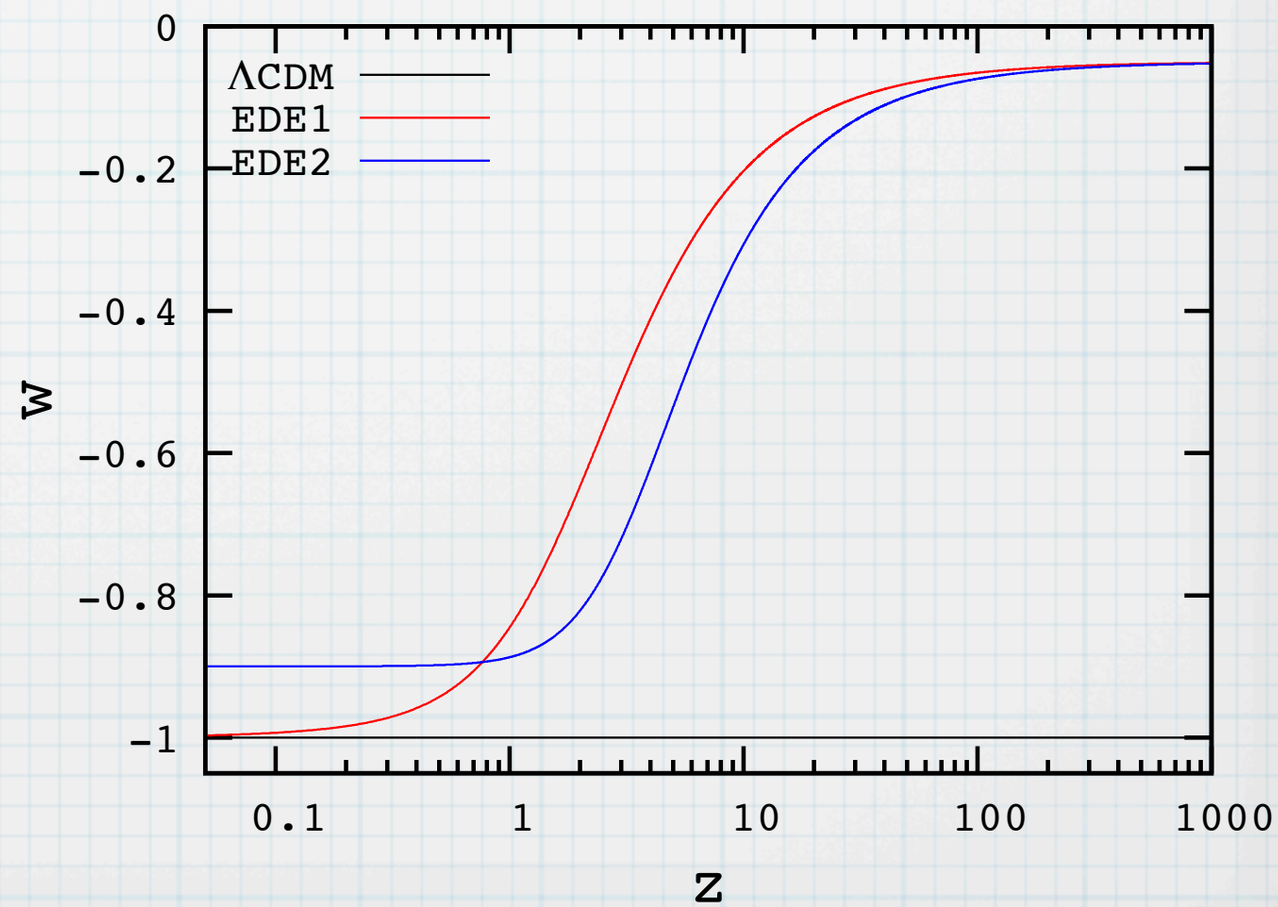
South Pole Telescope:

- Sunyaev-Zel'dovich effect
- Band: 95/150/220 GHz
- Start date: 2008
- Sky coverage: 4,000 deg^2
- $S_{min} = 10$ μK

Early dark energy

- Standard cosmological scenarios imply that dark energy amount is negligible at high redshifts.
- However, if we abandon LCDM that need not be the case, and models where DE is 1% level or more of the total density we call EDE.
- Theory is not a good guide for what model is reasonable; observations show $\Omega_{DE} \ll 1$ for $z \gg 1$, and $w_0 \approx -1$.





Dark energy perturbations

- Self-consistent treatment of dark energy perturbations
- Consider DE as an additional fluid:

$$ds^2 = a^2(\eta)\left[(1+2\Psi(\mathbf{x},\eta))d\eta^2 - (1+2\Phi(\mathbf{x},\eta))\delta_{\alpha\beta}dx^\alpha dx^\beta\right]$$

$$\delta_i' = -3\mathcal{H}(c_{s,i}^2 - w_i)\delta_i - \left[1+3\mathcal{H}(c_{s,i}^2 - c_{a,i}^2)\right](1+w_i)\frac{v_i}{k} - 3(1+w_i)\Psi'$$

$$v_i' = -\mathcal{H}(1-3c_{s,i}^2)v_i + \frac{kc_{s,i}^2}{(1+w_i)}\delta_i - kA$$

$$\eta = \int_0^t \frac{dt'}{a(t')}\ ; \qquad \mathcal{H} = \frac{a'}{a}\ ; \qquad c_{a,i}^2 = \frac{\partial p_i}{\partial \rho_i}$$

Dark energy perturbations

- Self-consistent treatment of dark energy perturbations
- Consider DE as an additional fluid:

$$ds^2 = a^2(\eta)\left[(1+2\Psi(\mathbf{x},\eta))d\eta^2 - (1+2\Phi(\mathbf{x},\eta))\delta_{\alpha\beta}dx^\alpha dx^\beta\right]$$

$$\delta_i' = -3\mathcal{H}(c_{s,i}^2 - w_i)\delta_i - \left[1+3\mathcal{H}(c_{s,i}^2 - c_{a,i}^2)\right](1+w_i)\frac{v_i}{k} - 3(1+w_i)\Psi'$$

$$v_i' = -\mathcal{H}(1-3c_{s,i}^2)v_i + \frac{kc_{s,i}^2}{(1+w_i)}\delta_i - kA$$

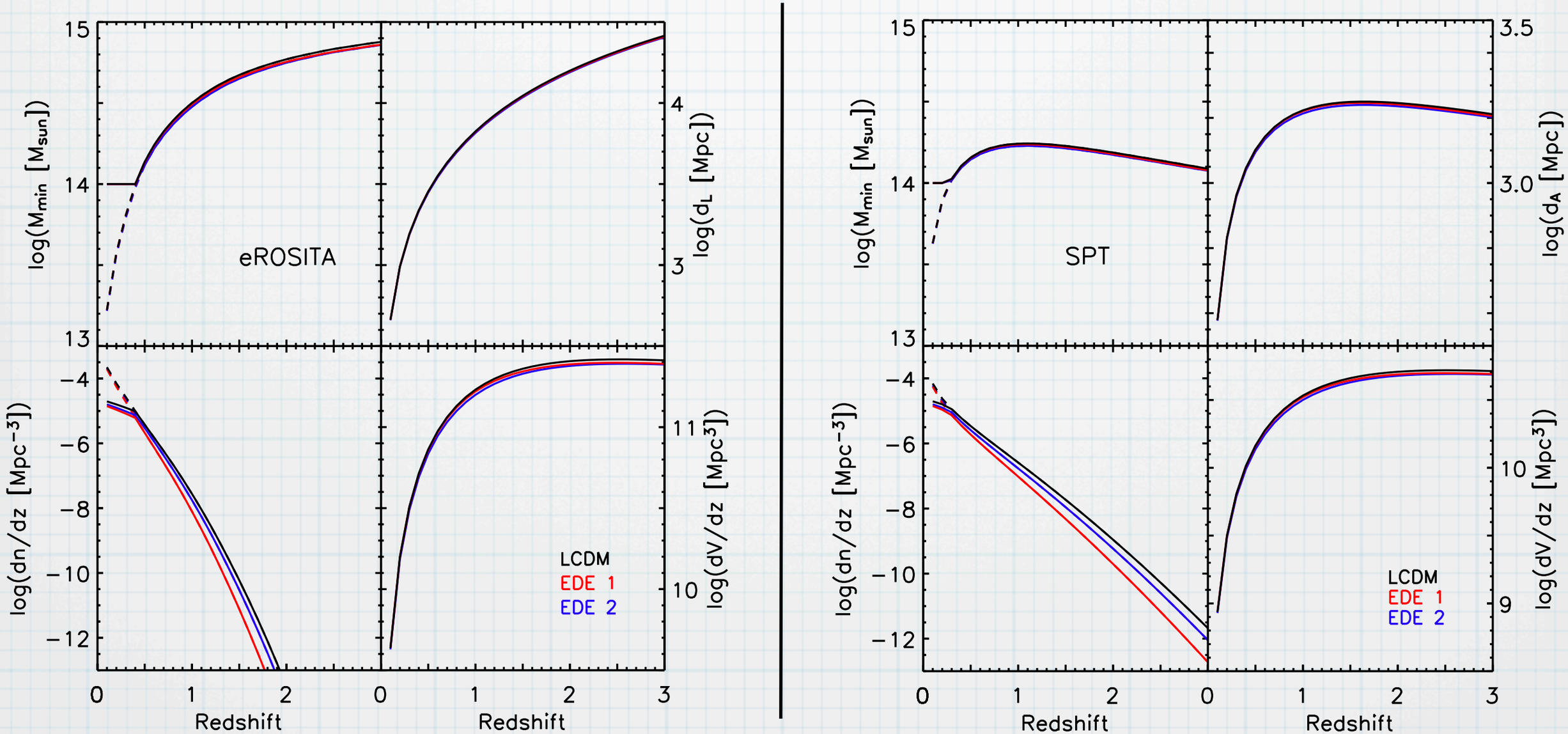
w≠-1 perturbations!

$$\eta = \int_0^t \frac{dt'}{a(t')}\ ; \qquad \mathcal{H} = \frac{a'}{a}\ ; \qquad c_{a,i}^2 = \frac{\partial p_i}{\partial \rho_i}$$

X-ray vs. SZ survey

LCDM: WMAP7+BAO+H_0 (Komatsu et al. 2009)

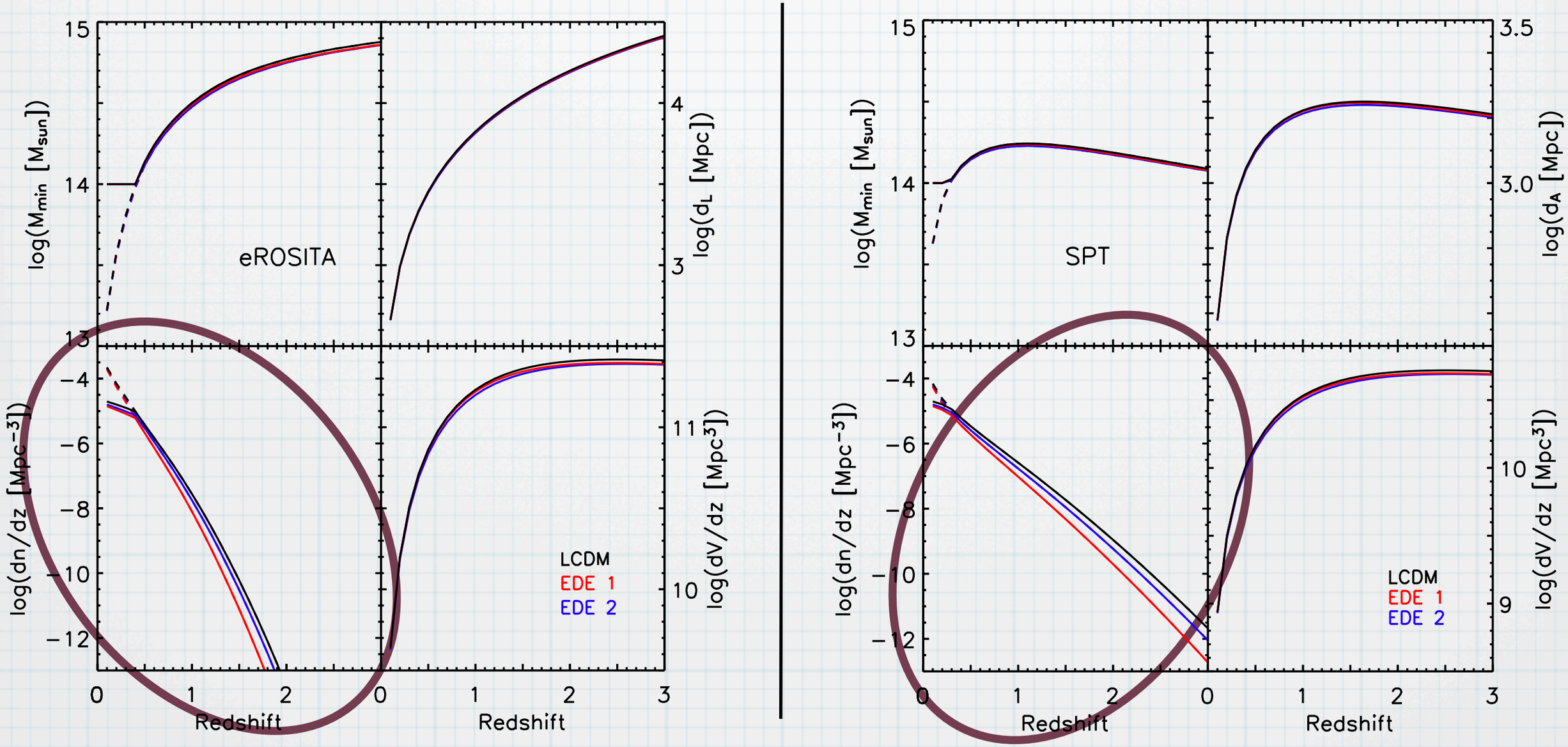
EDE1: w_0=-1, EDE2: w_0=-0.9 edge of current EDE constraints (Alam 2010)



X-ray vs. SZ survey

LCDM: WMAP7+BAO+H_0 (Komatsu et al. 2009)

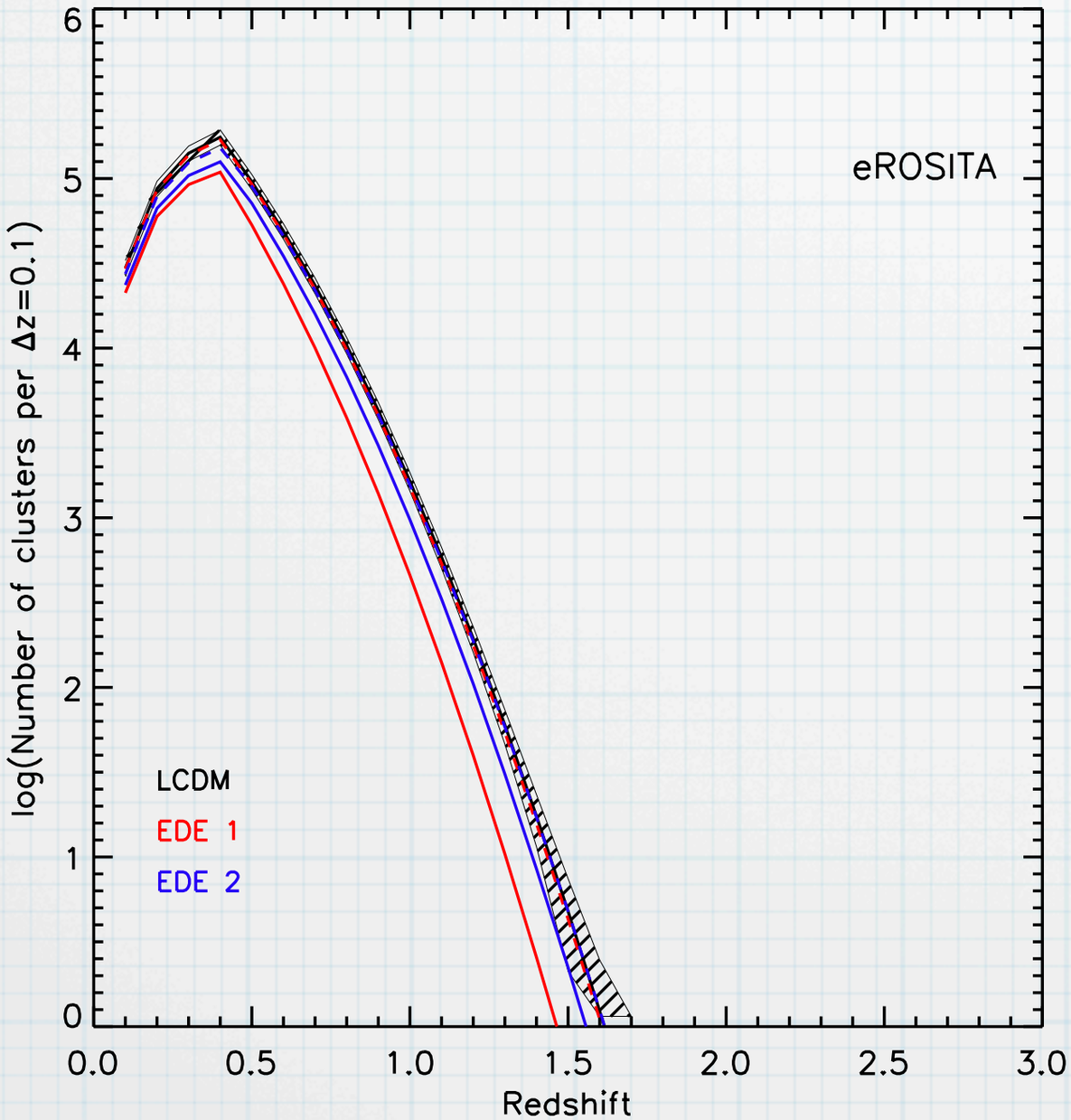
EDE1: w_0=-1, EDE2: w_0=-0.9 edge of current EDE constraints (Alam 2010)

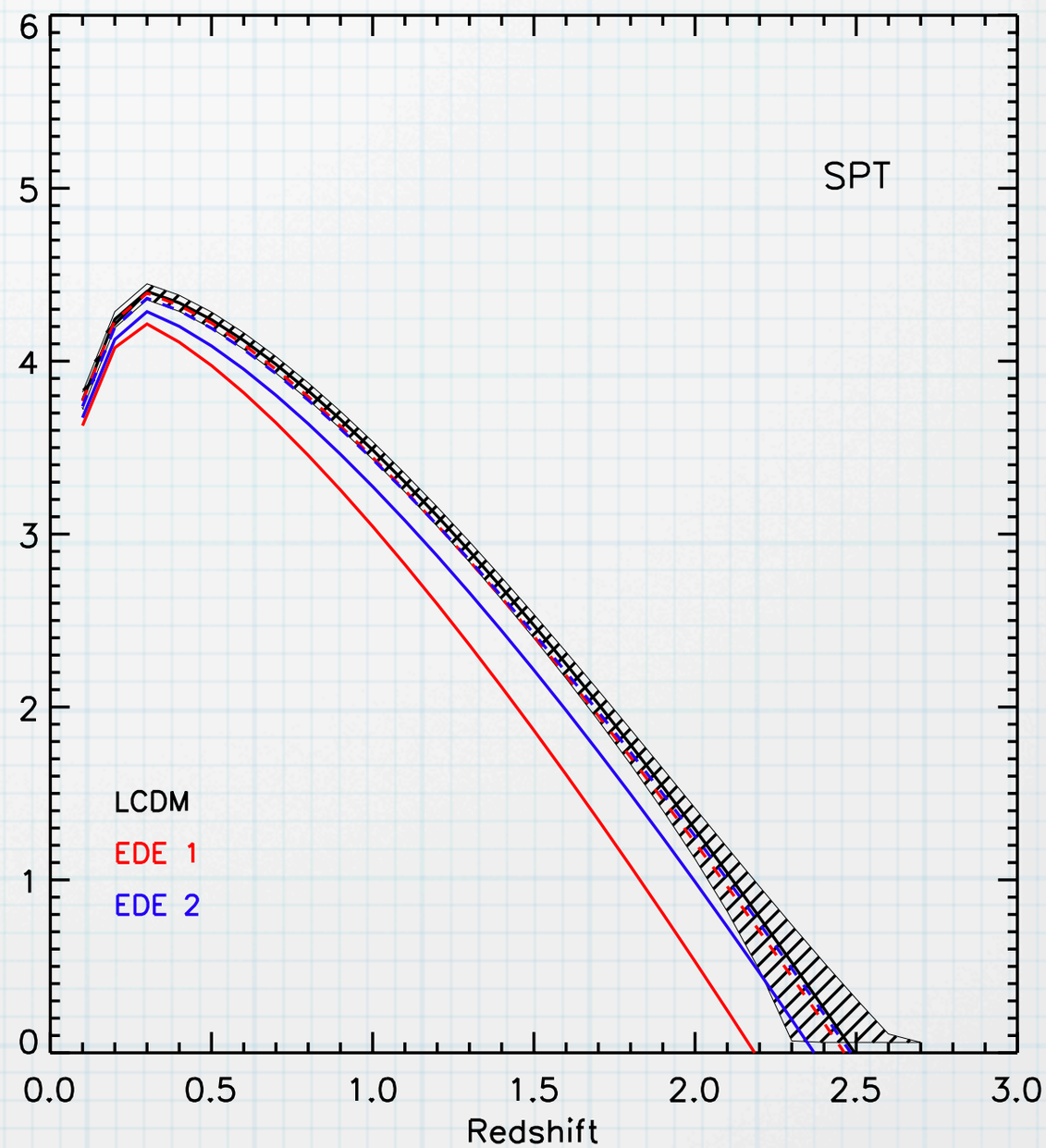


Cosmological sensitivity comes mostly from comoving abundance!

Cluster counts

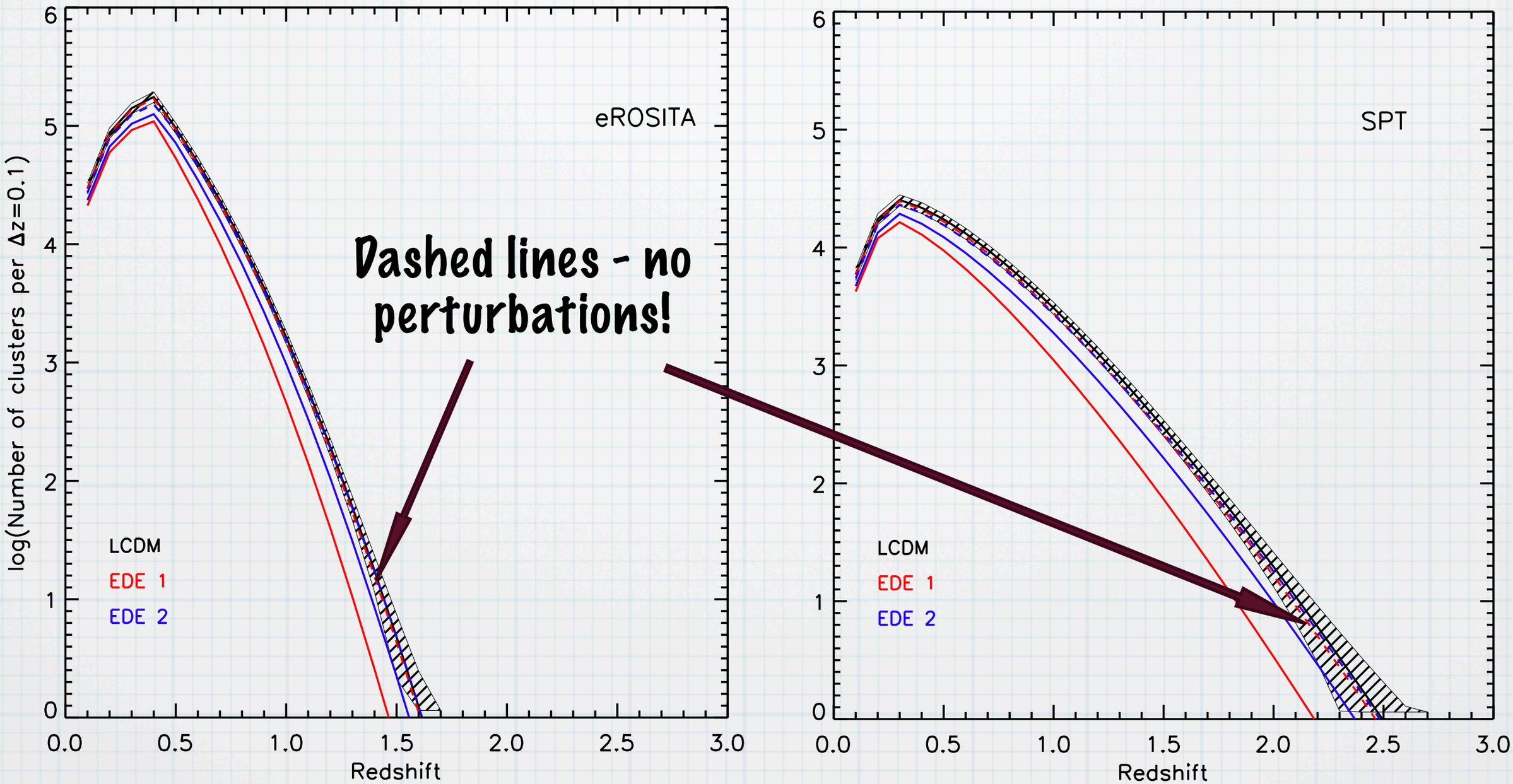
- EDE models not ruled out by current data can be ruled out using cluster counts. Constrains on transition redshift!



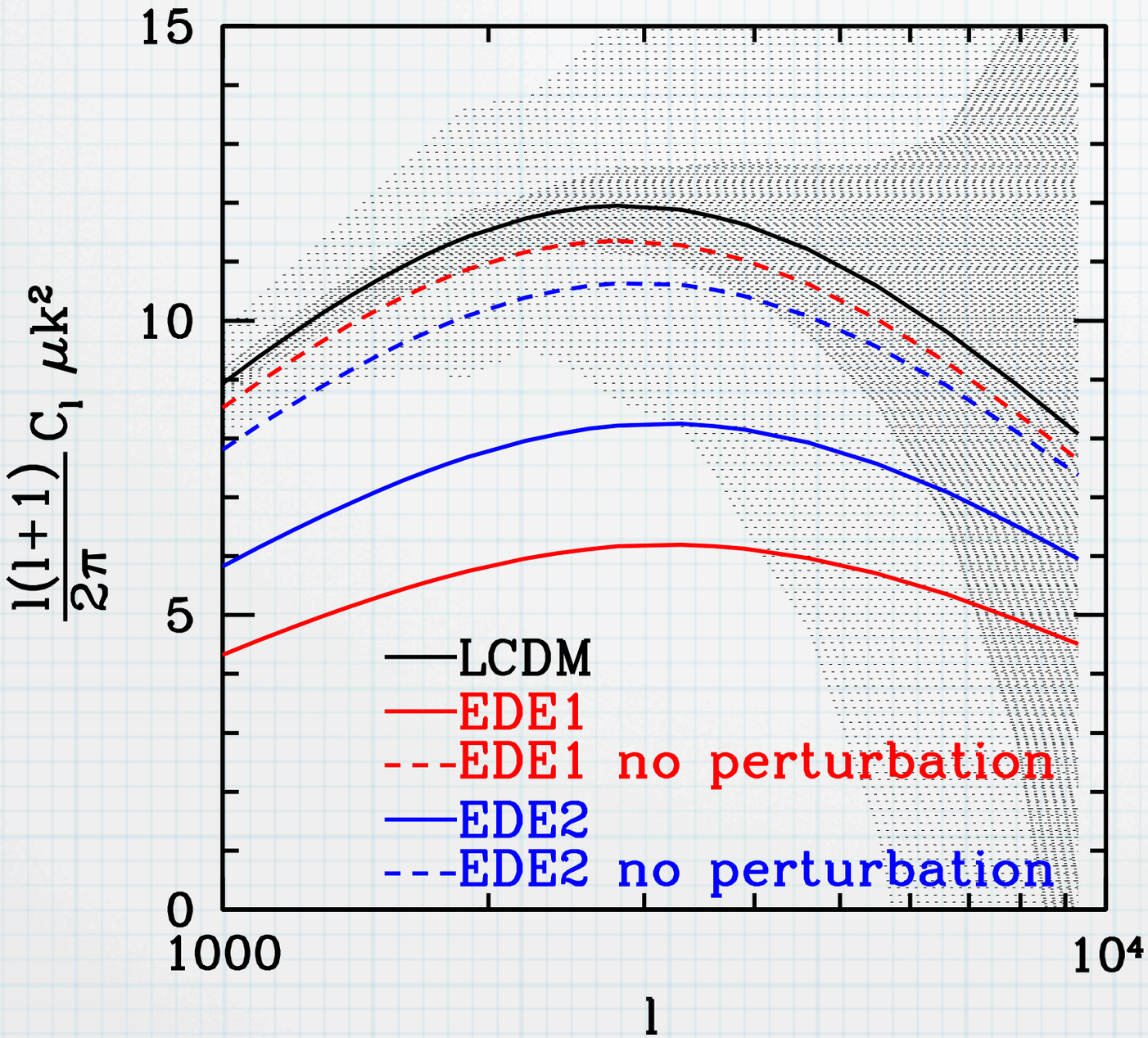


Cluster counts

- EDE models not ruled out by current data can be ruled out using cluster counts. Constrains on transition redshift!



SZ power spectrum

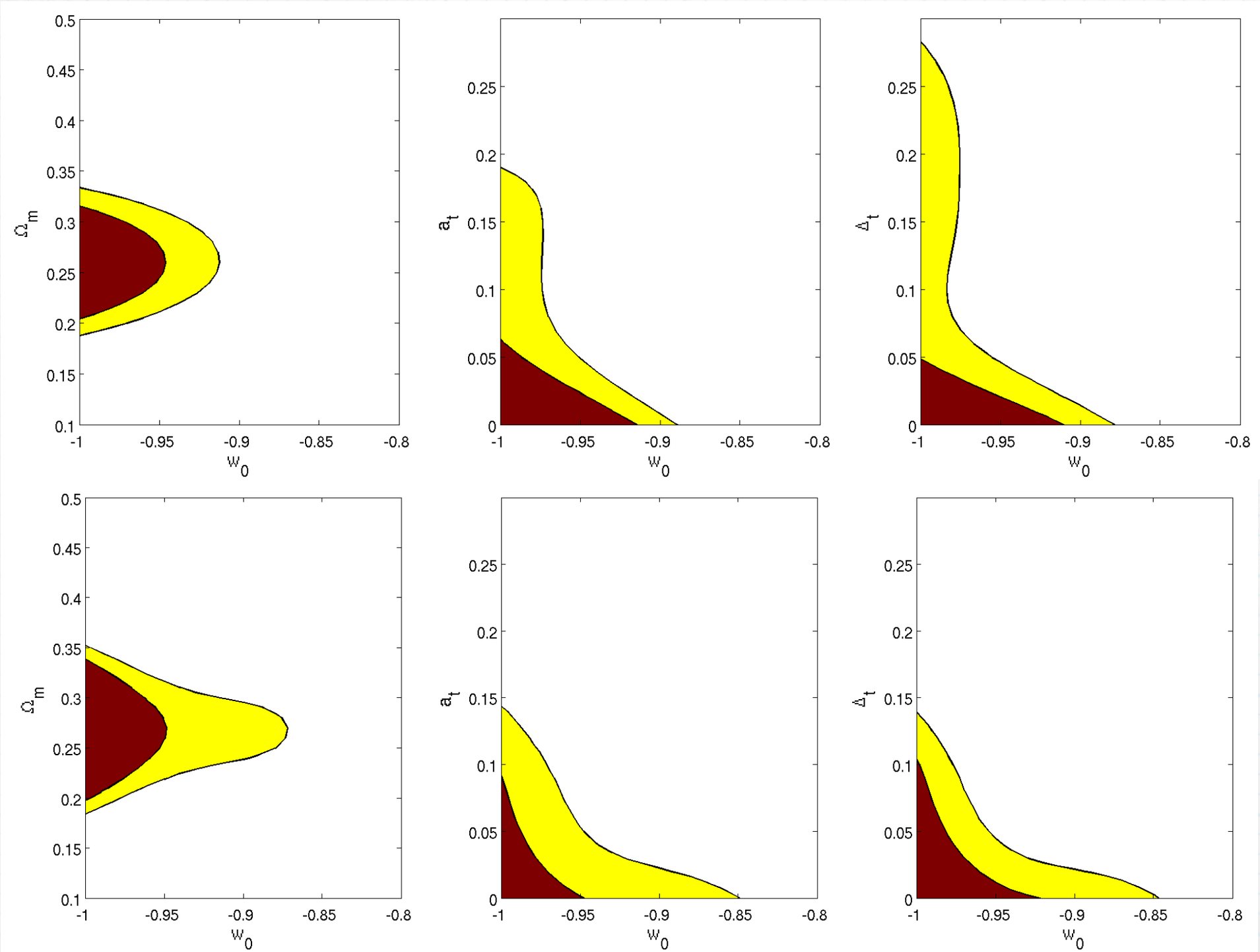


- CMB signal at few arcminutes scales.

- Planck full sky survey and SPT/ACT.

- Perfect removal of contaminants (e.g. radio laud galaxies), as well as perfect removal of primary CMB.

MCMC analysis



Cluster counts

SZ power spectrum

The End